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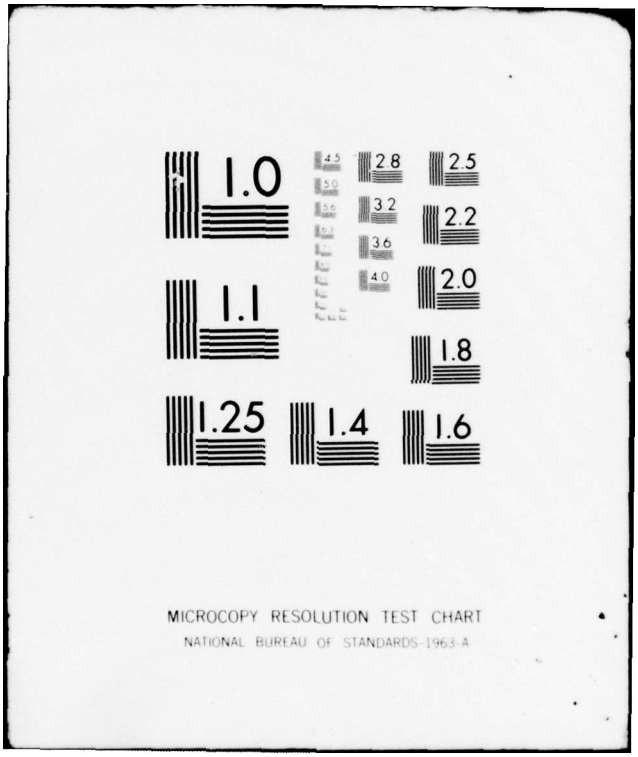
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University of Oregon

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Abstract

The concept of time-sharing as a general unitary ability has recently come under attack from several sources. The most serious of these appears in the work of Sverko (1976) who argues against the existence of a general time-sharing ability based on a failure to obtain correlations in the extent of dual-task performance decrement across task pairings. One of the reasons why these difficulties have arisen is that we do not have a clear theoretical picture of the nature of the processing limitations that underlie multiple-task performance. The major objective of the three experiments reported here was to further our understandings of the nature of these limitations. The results of the experiments lead to the conclusion that time-sharing is not a single general ability, but rather is dependent upon several more specific, and perhaps independent, processing limitations. These include: (1) an inability early in practice to simultaneously select, or retrieve, multiple responses from memory; (2) a persisting inability to initiate multiple independent responses simultaneously; (3) an inability to process, or at least efficiently process, contiguous inputs from separate modalities owing to the need for a modality-specific attentional focus; and (4) an inability to efficiently process multiple inputs from within the same modality owing to the existence of structural interference. It is suggested that the prediction of performance on complex criterion task combinations such as entailed in piloting or air traffic control requires specification of which of these component abilities is required by the criterion situations, and the tailoring or predictor tasks based on this specification.

Introduction

The efficient performance of complex tasks such as piloting or air traffic control operation would seem to require an ability to simultaneously monitor and respond appropriately to a variety of signal sources varying in location, modality and momentary importance. An appreciation of the apparent significance of a general time-sharing ability in the performance of skills requiring high rates of information exchange between the operator and his environment has recently led some researchers in abilities assessment to advocate a "parallel" approach to the prediction of performance (Passey & McLaurin, 1966; Waldersen, 1964; Dannhaus & Halcomb, 1975; Pew & Adams, 1975). The measure of principle interest in this approach is defined by the performance decline observed between conditions where a task is carried out singly and those in which the same task is carried out concurrently with at least one other. The less the decline, the better the individual's general time-sharing ability, as distinct from his ability to carry out any one of the component tasks alone.

Despite its obvious face validity, the basic assumption underlying this approach -- that there exists a time-sharing ability which is general and can be assessed through the simultaneous presentation of any two or more sufficiently demanding tasks -- has come under severe attack. In what follows, we will review the data that have been used to question the notion of a general time-sharing ability, and discuss some alternative interpretations of these data. We will then describe an alternative approach to the understanding of the time-sharing concept and report three experiments embodying this approach.

The criticism that has recently been leveled against the time-sharing notion concerns three issues. First, we may inquire as to whether there exists a general, transsituational, time-sharing ability. Is it rather the case that the pattern of individual differences observed under concurrent task conditions

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varies with the particular set of tasks studied? Second, we may ask whether time-sharing as either a general or a specific behavioral characteristic is an ability or a skill? That is, even if we can identify a set of component tasks to which we wish to predict, will measures derived from our predictors capture a relatively enduring ability, or simply index the subject's skill level at a given level of training? If the latter is true, it might prove difficult to predict steady-state levels of criterion performance on complex tasks based on any reasonably cost-effective set of predictor variables. The third issue relates to the assumption underlying most efforts to study time-sharing that there necessarily exists either system-wide or stage-specific capacity limitations which preclude interference-free processing of multiple signal sources. Indeed, time-sharing may be viewed as an ability to minimize such interference. An alternative view is that it is preparation for the sequencing of operations required for the performance of a task rather than any stage of task processing per se that requires capacity (Logan, 1978). If this were true, much of the effort that has been expended in search of the bottleneck(s) in information processing has been misdirected.

The question of whether time-sharing is in fact a general, transsituational ability has been raised by the results of an interesting study recently reported by Sverko (1976) Sixty subjects were tested on four information-processing tasks presented singly and in all possible pair-wise combinations. The tasks were chosen because of their simplicity of administration and the fact that they presumably tap different psychomotor and mental functions. The tasks included: 1) Rotary Pursuit, where the dependent measure was time-on-target; 2) Digit Processing, a 10-choice, self-paced choice reaction time task, where the dependent measure was response speed; 3) Mental Arithmetic, in which the subject counted backwards by threes, yielding a measure of the number of correct counts per minute; and 4) Auditory Discrimination, a two-choice, serial reaction time

task in which the subject was required on each trial to discriminate two tones differing in pitch, yielding a latency measure. All task pairings were performed under equal task priority instructions.

Sverko used two separate procedures to assess the transsituationality of the time-sharing obtained in the pairing of these tasks. First, the performance of subjects on each task under each pairing condition was correlated with that observed under all other conditions. The resulting intercorrelations matrix was then subjected to a principle component analysis. If a general time-sharing factor was present in the data five factors should have emerged, four task-specific factors and the general time-sharing factor. In fact, only four substantial factors could be extracted, and these were clearly task-specific. Second, a total performance decrement score was calculated for each task pairing. This score is simply the sum of the proportionate performance loss of the two tasks when paired, relative to when they were carried out singly. These scores were then correlated for the three possible nonoverlapping task pairings (i.e. A & B vs. C & D; A & C vs. B & D; A & D vs. B & C). The obtained correlation in all three cases was essentially zero, ranging from - .068 to .060.

These results leave open at least two possible interpretations. First, as proposed by Sverko, there may exist no general time-sharing ability. Thus if one wishes to assess an individual's ability to carry out the time-sharing demands of a particular criterion situation, the predictor variables used must be based upon task components derived directly from the criterion. Second, it is possible that time-sharing is not a single general trait, but rather is comprised of several more or less independent subabilities, some combination of which is functional for a given subject in a given multiple-task situation. One can imagine at least three types of subskill which might be called into play under time-sharing conditions: 1) an ability at some stage or stages of the information-processing sequence to parallel process multiple information sources; 2) an ability

to quickly and efficiently switch attention (re-allocate processing resources) between multiple sources during stages where processing must be carried out serially; and 3) an ability to automate, or remove from attentional control, the processing of one or more sources of information at some stage or stages. Sverko's task selection and analysis make it impossible to choose between these alternative interpretations. However, his results do force the important conclusion that there exists no unitary general (transsituational) time-sharing ability.

The second issue we wish to consider relates to whether time-sharing is a more or less stable ability (or aggregate of abilities) as opposed to a practice-dependent skill. Recent findings by Damos and Wickens (1977) have been interpreted as showing that time-sharing is a skill. Three groups of subjects were studied. On day 1: a) Group 1 simultaneously performed two tasks, short-term memory for visually presented digits and classification of simultaneously presented digit pairs; b) Group 2 performed the two tasks sequentially; and c) Group 3 did not perform. On day 2 all three groups simultaneously and successively (alternate blocks) performed on two independent one-dimensional compensatory tracking tasks, each of which required the centering of a cursor in a horizontal track by appropriate left-right manipulations of a control stick.

Two specific experimental questions were asked. First, during the dual-tracking portion of the study, are there improvements with practice in dual-task performance that are above and beyond improvements observed on each component task carried out alone? Second, does Group 1 show transfer of time-sharing skill from day 1 to day 2? The answer to both questions was affirmative, indicating quite clearly that there exists a skill component to time-sharing. It must be emphasized, however, that these results say nothing regarding whether or not time-sharing is an ability or set of abilities. Thus time-sharing ability patterns may set the range of multiple-task performance an individual can exhibit, and practice determines where in that range he/she is located at a given point in

time. A second point of interest in the Damos and Wickens study is the transfer of time-sharing skill from one task combination to another, implying [illegible]ralizability of the skill component of time-sharing.

The third issue we will consider regards whether the performance decrements observed [illegible] dual-task conditions reflects interference during the processing of stimuli, or rather delays introduced during task preparation prior to stimulus onset. The latter view has been promoted by Logan (1978) based on an extensive series of experiments seeking to identify the locus of interference effects during some stage or stages of stimulus and/or response processing. Logan's experimental strategy is an interesting one. On each trial in each of 6 experiments subjects were presented with an array of 4 to 8 letters through which he/she had to search for a prespecified target set. On some trials the visual search task was carried out alone and on other trials it was carried out concurrently with a short-term memory load. The memory load, a set of words, was exposed to the subject shortly before presentation of the visual search array. Recall was required following the visual search response on each trial. An additive factors logic was used to determine the locus of memory load effects in visual search. In brief, this logic runs as follows: within a particular experiment some variable or variables is manipulated which is believed on theoretical grounds to influence a particular stage or set of stages of information processing. If memory load (the time-shared task) influences the stage or stages manipulated, the effects of the memory load should interact with the effects of the variables manipulated. If memory load does not affect this stage, then its effects should be additive with those of the manipulation(s) in question (Sternberg, 1969). By this logic, Logan sought the locus of time-sharing decrements in four processing stages thought to underlie visual search: stimulus encoding, comparison (between array elements and target set), decision (as to whether comparison results in a match or mismatch), and response selection (following target detection). Memory load interacted with manipulations of none of the four stages, leading

Logan to conclude that none of the stages requires attention. However, memory load did produce overall declines in visual search performance under all experimental manipulations. Logan proposed that the seeming paradox here -- that memory load affects visual search performance, yet shows effects on none of a presumably exhaustive set of processing stages underlying that performance -- can be resolved by assuming that it is preparation for a component task rather than the stimuli associated with each task that requires capacity or attention. The function of such preparation is presumably to organize a sequence of structures that will enable the efficient processing of the task stimulus. Once preparation is complete, ..."behavior in reaction time situations...appears to be nothing more than a prepared reflex." (Logan, 1978, p. 59)

One can raise several questions regarding Logan's analysis. Granted that pre-task preparation is attention-demanding, what stages of processing require preparation? If a person finds him/herself unprepared for a particular task, presumably that preparation must be carried out following onset of the task stimulus. Again, what stages of processing require an attentional investment under conditions where the subject is ill-prepared? A more serious question must be raised regarding one rather basic supposition underlying Logan's interpretation. The supposition is that subjects continued to process information associated with the memory-load task during the stimulus-response interval of the visual search task imposed on each trial. It is only under those conditions where this assumption is met that one can assess the stage-wise attentional demands of dual-task performance. Unfortunately, Logan's subjects had available an alternative course of action: they may have interrupted processing of the memory load task at or near onset of the visual search array, and reinstated processing of this material only after the attentional demands of the search task were completed. Assuming subjects could not always interrupt processing of the memory task precisely at the point where the search task required attention, this strategy would fully acount for Logan's data. Accordingly, it remains

equivocal whether or not any one or more of the information-processing stages examined by Logan actually require attention.

In summary, it seems clear from our treatment of the studies of Sverko (1976), Damos and Wickens (1977) and Logan (1978) that an assessment of the nature and potential applied function of the time-sharing concept will be adequate only to the extent that it meets at least the following three requirements. First, one's assessment procedure should possess the capability to control, or at least measure, the effects of strategic factors in the determination of (dual-task) performance. Failures in this regard were apparent both in Sverko's study and in that of Logan. Second, one's procedure should be analytic with respect to (a) the stage(s) of processing that are affected under time-sharing conditions, and (b) whether time-sharing efficiency with each stage examined is determined by the subject's ability to parallel process multiple requirements (Hawkins, 1969), or his/her ability to quickly and efficiently shift attention between the requirements (Gopher & Kahneman, 1976). Logan's procedure met the first of these requirements. Sverko's met neither. Third, following the findings of Damos and Wickens (1977), one's procedure should include provision for separating the skill and ability components of time-sharing performance.

The procedure described in this report represents an initial attempt to meet these three requirements. Within this procedure, the double-stimulation or psychological refractory period (PRP) paradigm, two stimuli each requiring a unique response are presented on each trial. One of the stimuli, S_1, always onsets at or shortly prior to the onset of the other, S_2. In our experiments the interval between stimuli, ISI, varied between zero and 1200 msec. The type of task signaled by the stimuli varied somewhat from experiment to experiment, though some form of choice reaction time is required by both Task 1 and Task 2. Figure 1 depicts the typical results of such a procedure. The two functions shown reflect response latencies to Task 1 and Task 2, respectively,

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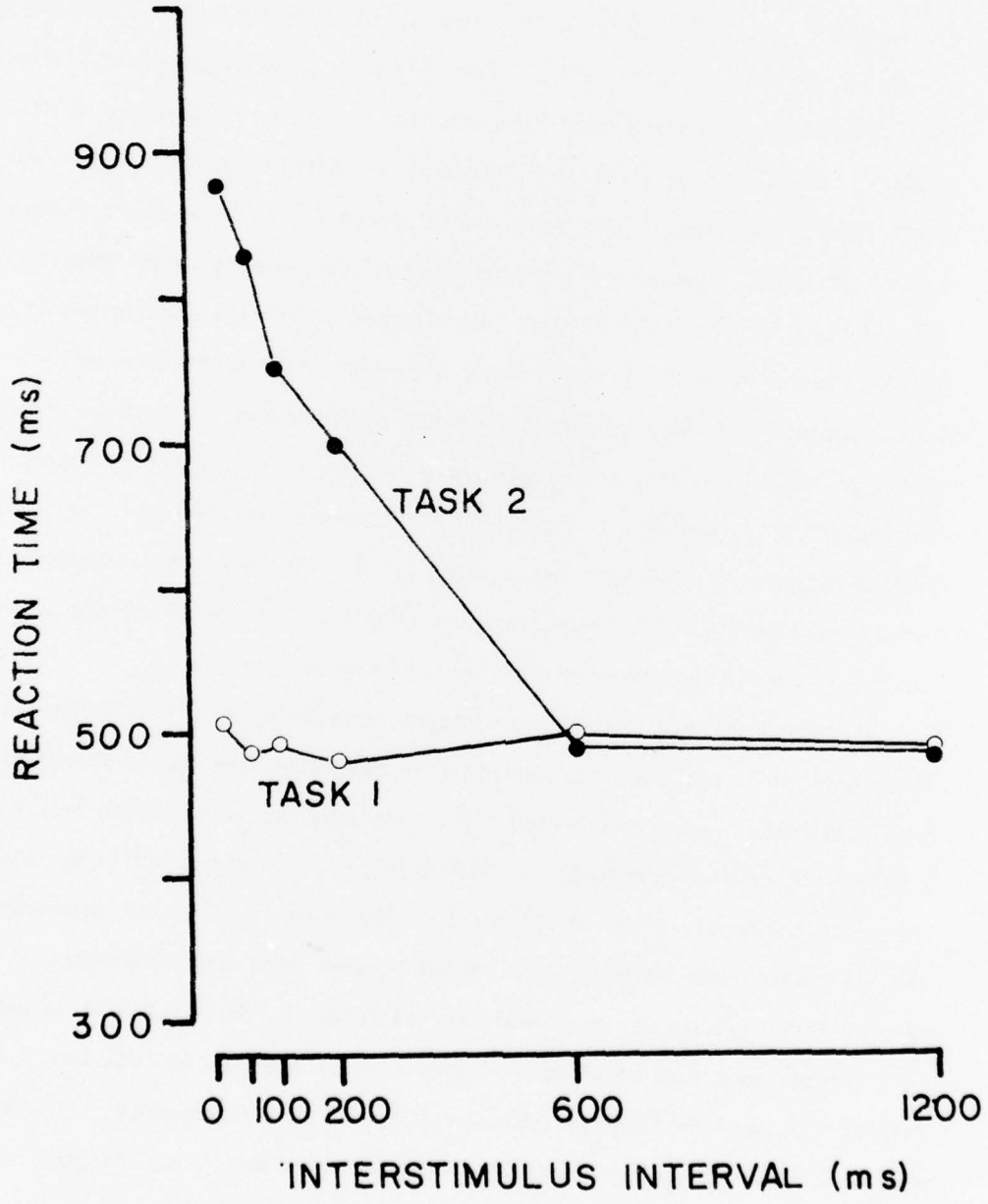
Figure 1

Task 1 and Task 2 reaction time as a function of inter-stimulus interval.



as a function of ISI. The latency increase for Task 2 apparent at the short ISI values is characteristic and is commonly referred to as the PRP effect. This effect manifests some form of interference in Task 2 processing that is produced by the processing demands of Task 1. In the experiments that follow we will attempt to show that variations on the basic paradigm that produced the data of Figure 1 may be used to ask questions about time-sharing phenomena in a way that is subject only minimally or not at all to the problems we have raised. In the first experiments we reexamine the issue raised by Logan (1978) which concerns whether or not attentional mechanisms must be called into play during the processing of a signal. Experiments II and III were designed to isolate the loci of interference in double-stimulation situations and to assess the effects of practice on the extent and nature of such interference.

Experiment I

The PRP effect shown in Figure 1 is not inconsistent with Logan's (1978) idea that it is preparation for rather than the actual performance of a task that requires attention. In Logan's view the PRP effect results because the subject invests the time prior to each trial preparing for Task 1 and does not begin, or at least does not complete, preparation for Task 2 until some point shortly following onset of stimulus 1. Presumably the actual processing of stimulus 2 does not begin until after this preparation is completed, and therein lies the source of the PRP effect. Note that since the actual processing of a stimulus does not require attention, preparation for Task 2 can begin at or near the onset of stimulus 1, unaffected by Task 1. The logic of Experiment I follows from these considerations. Task 1 consists of two 2:1 S-R mappings. One of the stimuli within each mapping occurs with a probability of .45, while the other occurs with a probability of .05. Task 2 consists of two 2:1 mappings, with equiprobable stimuli and responses. Task 1 reaction time (RT) will vary as the inverse of stimulus probability within response sets (Hawkins, et al., 1974).

If the additional processing required by the lower probability stimuli in Task 1 does not require attention, as assumed in the Logan account, then it should not affect preparation time for Task 2. Therefore, Task 2 RT should remain constant across levels of Task 1 difficulty.

Method

Subjects. The subjects were 6 men and 9 women drawn from the University of Oregon paid subject pool. All reported normal or normal-corrected vision.

Procedure. Stimuli were displayed on a computer-controlled cathode ray tube situated in a small darkened subject cubicle. The subject was seated about 65 cm in front of the CRT display with the middle and index fingers of each hand resting on a piano-type response key. Each trial began with the exposure of a fixation cross which remained in view for 750 msec. Stimulus 1 appeared .5° to the left and simultaneous with the offset of the fixation cross. Following an interstimulus interval (ISI) of either 0, 50, 100, 200, 600, or 1200 msec, stimulus 2 appeared .5° to the right of fixation. Both stimuli remained in view for 500 msec. The two stimuli subtended a visual angle of 1.6°. Task 1, signalled by stimulus 1, consisted of four stimuli mapped in a 2:1 relationship into two equally probable responses. One of the stimuli assigned to each response occurred with high (.45) and the other with low (.05) relative frequency. The stimuli used by each subject in task 1 were the four upper-case letters K, B, H, and D. The subject's task was to respond to the task 1 stimulus by depressing one of the two left-hand response keys in accord with a prespecified S-R mapping.

Task 2, signalled by stimulus 2, consisted of four equiprobable stimuli mapped in a 2:1 relationship to two responses. Stimuli were digits drawn from the set 3,4,7 and 8. Subjects responded to stimulus 2 by depressing one of the right-hand keys as appropriate.

Instructions were to respond as quickly and as accurately as possible, and to treat task 1 as primary. To faciliate the latter objective, feedback providing Task 1 latency was given following each trial. Testing continued for four

consecutive days with 504 trials administered during each experimental session.

Results and Comment

Table 1 gives mean correct RT and percent incorrect responses for high and low Task 1 stimuli and Task 2 stimuli following high and low Task 1 stimuli at each of the levels of ISI. The data were subjected to an analysis of variance

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Insert Table 1 about here

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in which Task (Task 1 versus Task 2), ISI (0, 50, 100, 200, 600, and 1200 msec) and Task 1 stimulus probability (.45 vs. .05) were all treated as within-subjects variables. The analysis revealed that task, $F(1,14)=35.79$, ISI, $F(5,70)=194.50$; Task 1 stimulus probability $F(1,14)=17.3$, the interaction of task and ISI, $F(5,70)=11.05$; The probability X task interaction, $F(1, 14)=7.56$; and the interaction of all three factors, $F(5,70)=20.96$ were significant at less than the .01 level. Of major interest was the effect of Task 1 stimulus probability on Task 2 relative to Task 1. The interaction between Task and Task 1 stimulus probability indicates that the probability effect was actually greater under Task 2 than under Task 1. The three-way interaction shows that the magnitude of the differential effect of probability across tasks diminished with increasing ISI.

The results of this first experiment, therefore, demonstrate that Logan's analysis is incorrect, at least in the context of the double stimulation paradigm: the processing of the Task 1 stimulus requires attention or capacity and as a consequence, increasing the processing demands of the first task increases the magnitude of the associated delay in Task 2 processing.

Thus it is apparent that attention is required by some stage or stages of processing located between stimulus onset and response completion. This first experiment provides few clues, however, regarding the nature of locus of the effect. In addition, the results clearly do not preclude the possibility that task preparation also requires attention, as proposed by Logan.

Table 1

Reaction time and percent errors in Experiment I as a function of Task (1 or 2) and Task 1 stimulus probability (.45 or .05).

	ISI (msec)					
	0	50	100	200	600	1200
	Task 1					
High probability	481	479	469	463	456	454
Low probability	610	617	588	603	576	576
RT difference	129	138	119	140	120	122
	Task 2					
High probability	824	774	730	651	482	434
Low probability	988	927	871	787	512	453
RT difference	164	153	141	136	30	19

Experiment II

The second experiment represents an initial attempt to isolate the locus of the interference effects obtained in Experiment I. The procedure used is one first described by Karlin and Kestenbaum (1968). Task 1 in the Karlin and Kestenbaum study required a choice RT to one of two possible digits presented visually. In one condition the second task consisted of a simple (detection) RT to a 1000 Hz. tone. In another condition Task 2 required a choice RT on each trial to one of two possible tones differing in pitch.

With a variant of this paradigm we felt we could distinguish between two potential sources of the PRP effect. Our logic began with the following sets of assumptions: 1) the information-processing sequence in our CRT task consists of at least three discrete stages -- stimulus encoding, response selection and response initiation; and 2) stimulus encoding does not require attention. Stimulus encoding refers to all processes preliminary to stimulus identification. Our assumption that this stage does not require attention was based on the finding (Hawkins, 1969; Duncan, 1978) that under a variety of circumstances we seem able to extract visual information from multiple sources in parallel. Response selection refers to the retrieval from memory of the response associated with the stimulus presented on each trial. Response initiation refers to the translation of the retrieved response into motor action. The notion that response selection is the source of the interference observed in PRP situations is an old one consistent with the general idea that memory represents the point of greatest fragility among man's information processing capacities. The idea that response initiation is the source of the interference receives its most persuasive support from the Karlin and Kestenbaum study, to which we now return.

If we calculate the difference in latency that these researchers obtained between the easy and the more difficult second task as a function of interstimulus interval, we see that whereas the easy (simple RT) task enjoyed a relatively big speed advantage (81 msec) at the longest interval, its advantage was quite small

(27 msec) at the shortest. The latency difference at the longest interval is probably due to response selection (retrieval) time. If the increases in RT to the second task at short ISI levels (i.e. the PRP effect) were due to the fact that subjects cannot retrieve response 1 and response 2 simultaneously, the difference in latency between easy and difficult second tasks should have remained more or less constant across intervals. That is, response selection for easy and more difficult second tasks should have been delayed by the same amount at the short interval -- the time required for completion of Task 1 response selection. Since this was not the case, it would appear that the Karlin and Kestenbaum results are incompatible with the idea that response selection is the source of the PRP effect. Alternately, consider the possibility that the effect is due to interference in response initiation (Keele, 1973). If this were so, the reduction in latency difference between easy and difficult second tasks at the short ISIs is understandable. Again the assumption is that the difference between the two tasks at the longest ISIs is in response selection time. At the shortest intervals response initiation for both easy and the difficult second tasks must await the completion of response initiation for Task 1. The easier second task should lose some or all of its latency advantage over the difficult one during this waiting period because it must endure a longer wait. The longer wait is produced by the fact that response selection for the easier task will be completed prior to that for the more difficult task, and the duration of the wait is equal to the interval between completion of response selection for Task 2 and completion of response initiation for Task 1.

While the Karlin and Kestenbaum results seem to implicate response initiation rather than response selection as the bottleneck in information processing, two possible problems exist. First, the data reported by these workers were from subjects who had previously practiced for 5 days on the tasks involved. Thus, while their results may apply to highly overlearned S-R connections, they may not

be applicable to freshly learned ones. Second, it is possible that the convergence of Task 2 functions at the shortest ISIs in the Karlin and Kestenbaum study is due to a factor other than parallel response selection. Both Task 1 and Task 2 stimuli appeared on every trial of the Karlin and Kestenbaum experiment. Thus as the delay between stimulus 1 and stimulus 2 increased within a trial, the likelihood that stimulus 2 would occur at the next instant in time gradually increased up to the point of complete certainty at the longest ISI studied. The simple RT task used as the easier second task probably profited more from this progressive resolution of temporal uncertainty than did the more difficult choice RT task. If so, this could have produced the divergence of latency functions across levels of Task 2 difficulty observed at the longest ISIs in the Karlin and Kestenbaum study.

In Experiment II we used a variant of the Karlin and Kestenbaum procedure to look at these two issues. Subjects were tested for a total of 10 days, and data from all 10 experimental sessions were examined to look for possible changes in the attentional demands of response selection as a function of practice. In addition three levels of Task 2 difficulty were investigated. Two of these were similar to those used by Karlin and Kestenbaum. A third consisted of a more difficult choice RT task. Thus we could compare latency functions across levels of task difficulty (the two-choice RT tasks) without concern for the possible contamination caused by temporal uncertainty resolution.

Method

Subjects. Subjects were three undergraduate women drawn from the Psychology department's paid subject pool. All had normal or normal-corrected vision.

Procedure. The apparatus was identical to that used in Experiment I. Task 1 consisted of two stimuli selected separately for each subject from the letter set B, C, G, and Q, to which subjects made a choice reaction using two key-press responses. As in the first experiment Task 1 stimuli appeared to the left of

fixation and required a left-hand key response. Three different levels of TAsk 2 difficulty were studied. At the lowest difficulty level subjects responded to the onset of a stimulus appearing to the right of fixation by depressing a key located beneath the index finger of their right hand (simple RT). At the next level of Task 2 difficulty one of two digits appeared to the right of fixation on each trial and the subject made a speeded-choice reaction by depressing one of two right-hand response keys. At the highest difficulty level Task 2 consisted of six digits mapped in a 3:1 arrangement into the two right-hand key press responses. Task 2 stimuli were formed into the two response sets 3,5,8 and 2,5,9. The digit used for a particular subject as the stimulus in the simple RT task was that assigned to the subject's index finger response in the 1:1 choice RT task and was one of those assigned the same response in the 3:1 choice RT task. The identity of this digit varied arbitrarily across subjects. Interstimulus intervals and stimulus spacing were as in Experiment I. Subjects were tested under the instructions that Task 1 was primary and that their performance on this task should not vary across ISIs or levels of Task 2 difficulty.

Subjects were tested for about one hour on each of 10 days. A session consisted of six blocks of 84 trials, two at each Task 2 difficulty level. The order to Task 2 presentation was counterbalanced across subjects and sessions.

Results and Discussion

Figures 1a through 1c show mean RTs for Tasks 1 and 2 across ISI levels averaged across levels of training for each subject. The results have been averaged across levels of training because none of the data relationships appearing in the figures changes with practice other than overall speed.

While clear individual differences appear in response speed, relative speeds of Task 1 and Task 2, and magnitude of the PRP interference effect,

Insert Figures 2a - 2c about here

the data are otherwise in striking agreement across subjects. First, it will be

Figure 2a

Task 1 and Task 2 reaction time for subject LB as a function of inter-stimulus interval and level of Task 2 difficulty.

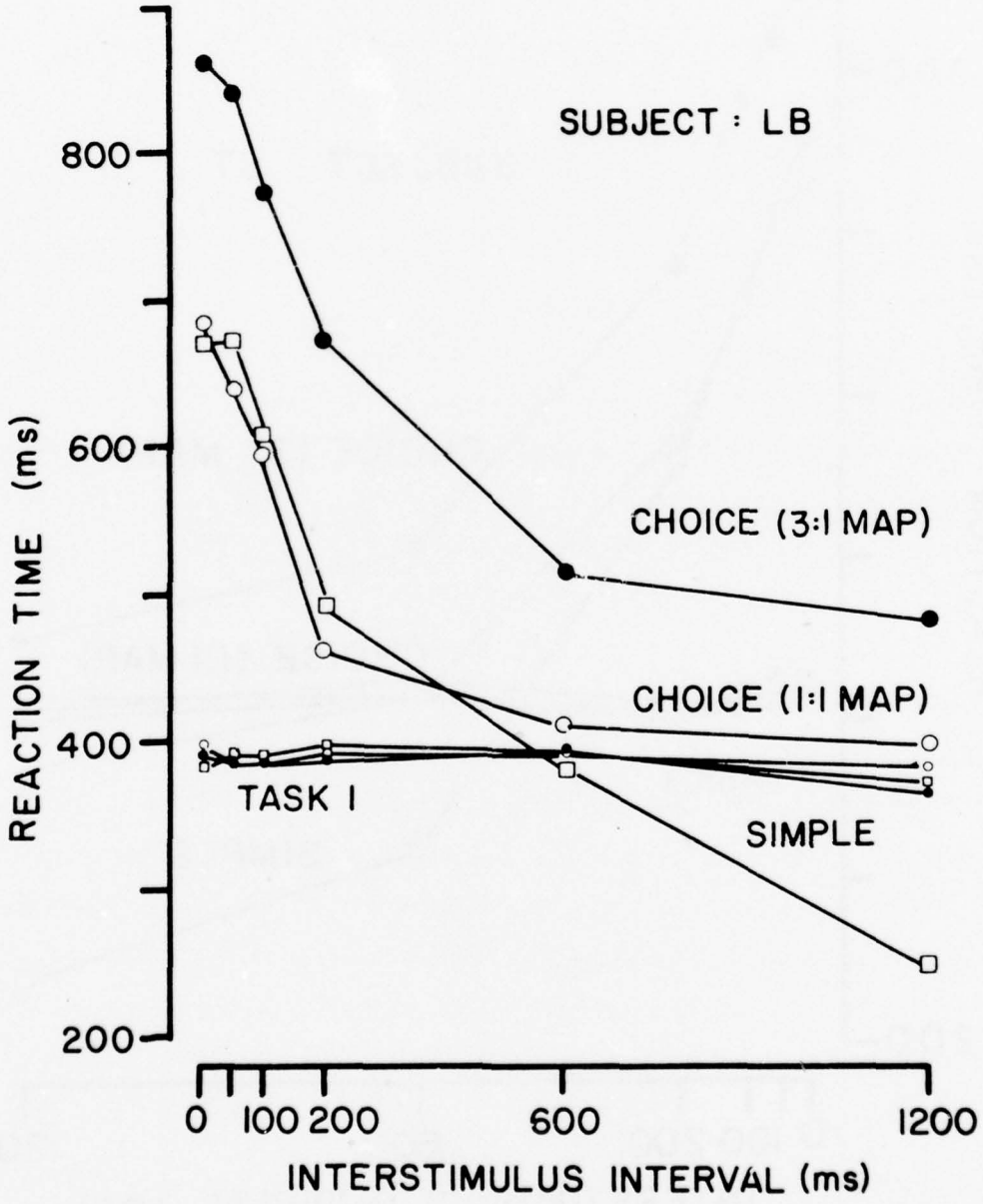


Figure 2b

Task 1 and Task 2 reaction time for subject ST as a function of inter-stimulus interval and level of Task 2 difficulty.

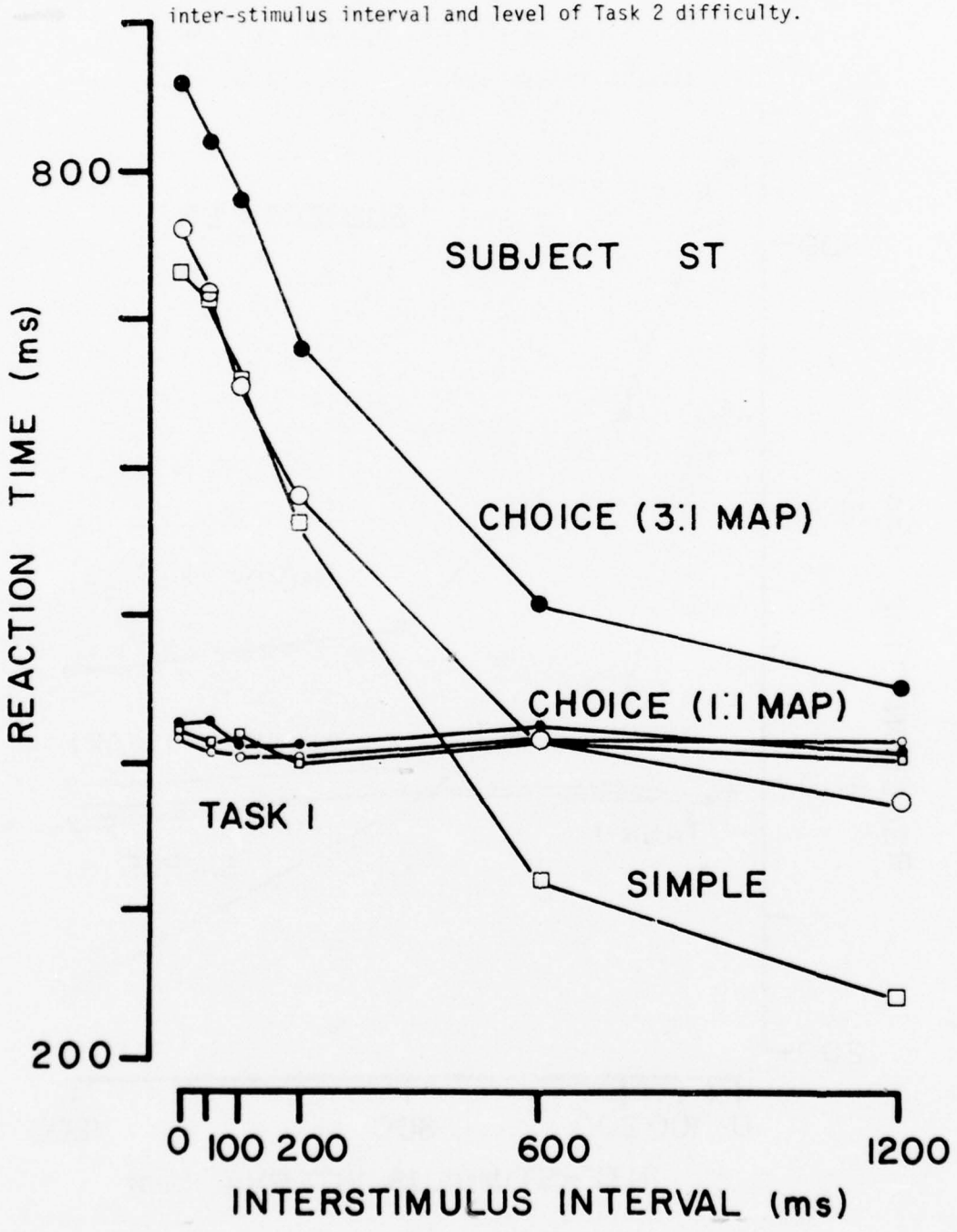
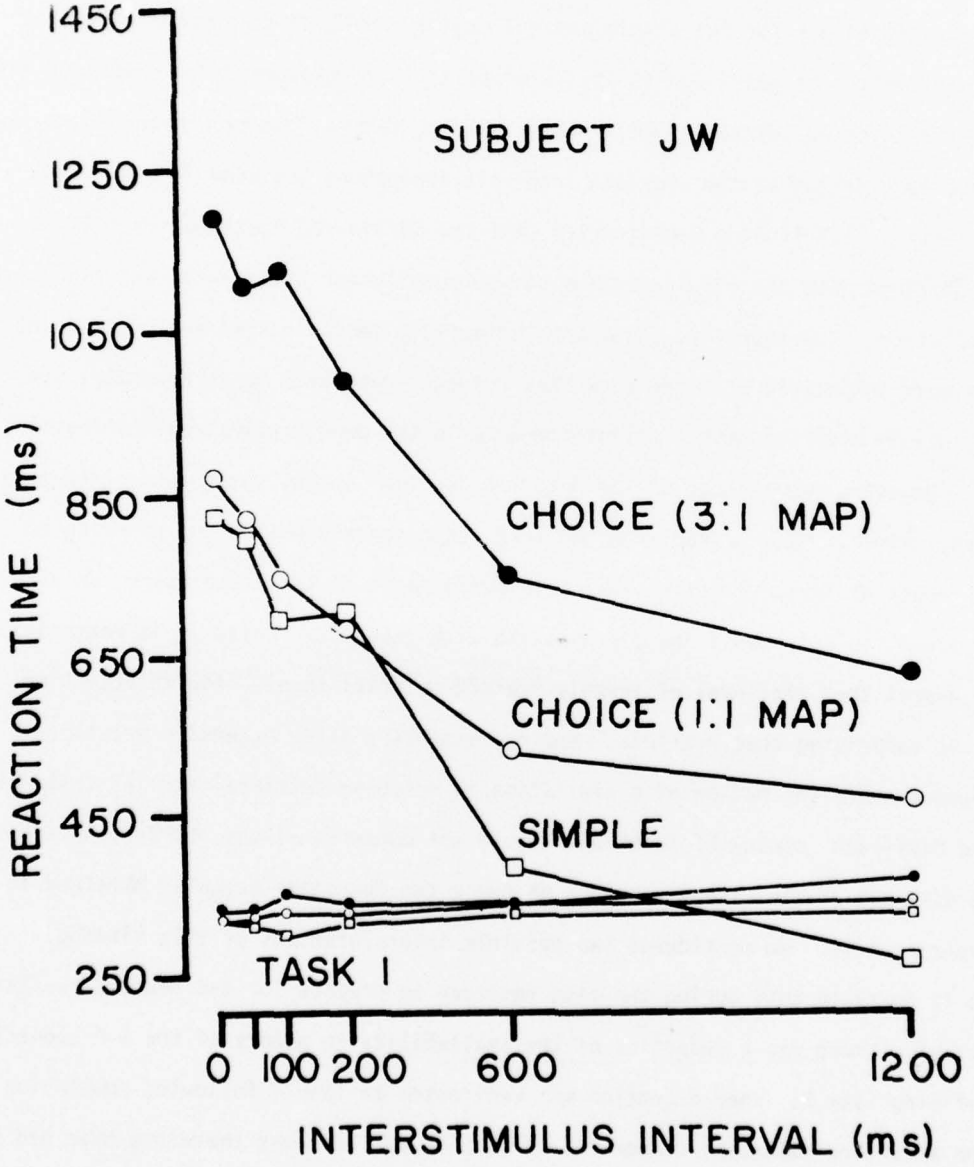


Figure 2c

Task 1 and Task 2 reaction time for subject JW as a function of inter-stimulus interval and level of Task 2 difficulty.



noted that subjects were generally able to follow the experimenter's admonition to hold mean Task 1 latency relatively constant across intervals and levels of Task 2 difficulty. This result implies that differences in Task 2 performance across ISIs and difficulty levels are wholly a function of those variables, not of changes of relative task emphasis. Second, a comparison of latency functions for the simple and the easier choice RT second tasks reveals a convergence, or under-additivity, similar to that obtained under like conditions by Karlin and Kestenbaum (1968). Surprisingly, though, the two choice RT functions actually diverged at the shortest intervals throughout training for all three subjects. This finding demonstrates that the Karlin and Kestenbaum result may not be obtained when one eliminates the possible influence of temporal uncertainty resolution. Consequently, one might tentatively conclude that the present data are most compatible with the idea that response retrieval is an important and relatively enduring source of interference in the double-stimulation situation.

However, two aspects of the data made us feel uneasy about this interpretation. First, while we had expected that response retrieval might prove to be an important factor limiting dual task performance in this experiment, we also expected its role would sharply diminish with practice. While it is reasonable to expect that retrieval of freshly learned material should require attention, it is surprising that retrieval requires attention after extensive practice. Second, while the notion of a limitation in response retrieval implies that easy and difficult choice RT functions should not converge at the shortest intervals, it does not predict the divergence of these two functions actually obtained in Experiment II. We considered two possible interpretations of this finding. It is feasible that during the time required to prepare for and process the Task 1 stimulus there was a reduction of the availability in memory of the S-R connection defining Task 2. When attention was redirected to Task 2 following completion of the attention-demanding components of Task 1, subjects may therefore have had to

regenerate the Task 2 connections by some time-consuming process. It is plausible that the time required by this process, or even its necessity, was greater for the more difficult, relative to easier, choice RT task. A second possibility is that although stimulus 1 and 2 were both presented foveally, some form of structural interference existed between the two stimuli within the visual system, and the extent of this interference was greater for the more difficult second task. That is, the disruption in stimulus 2 processing produced by the processing of stimulus 1 may have been more effective in the case where stimulus 2 could have been any one of six as opposed to either of two alternatives.

Experiment III

The third experiment was designed to examine these two possibilities. The effects of Task 2 difficulty were examined under two conditions of Task 1 presentation. Under one of these stimulus 1 was presented in the visual modality while in the other stimulus 1 was auditory. In both cases the Task 2 stimulus was visual. If the over-additivity observed in Experiment II were due to structural interference within the visual system the effect should occur under the visual/visual condition but not under the auditory/visual condition of the present experiment. If the effect were due to the necessity of differential Task 2 preparation (i.e., the regeneration of S-R correspondences), it should appear under both the conditions of the present study.

Method

Subjects. Subjects were eight students drawn from the University of Oregon paid subject pool. All had normal or normal-corrected vision, and none reported abnormalities in auditory functioning.

Procedure. Each subject was tested for a total of six experimental sessions, each of about 1-hour duration. A session consisted of four trial blocks of 84 trials each. During two blocks Task 1 stimuli consisted of 81 db SPL sinusoidal

tones, either 800 or 900 Hz in frequency. The task was to identify which of the two alternative frequencies occurred on each trial and to respond accordingly by depressing the appropriate left-hand response key. During the remaining two blocks Task 1 stimuli were the two upper case letters M and N, presented visually to the left of fixation as in the first two experiments. The task was to identify which letter appeared on each trial and to respond accordingly by depressing the appropriate left-hand response key.

During one trial block of each of the two Task 1 modality types, Task 2 required subjects to choice react to each of two possible digits presented to the right of fixation as in the previous two experiments. The stimuli, 3 and 4, were mapped into the two right-hand response keys in 1:1 fashion. During the other trial block under each modality type, Task 2 consisted of six digits and two responses in a 3:1 mapping arrangement. Digits were 2,4,9,3,6, and 8. All other features of the within-trial sequence were identical with those used in Experiment II.

Order of presentation of the four conditions formed from the combination of two Task 1 modality types and two Task 2 difficulty levels was countervalanced within subjects across days and across subjects.

Results

Table 2 gives the correct mean RT and percept incorrect responses (parentheses) for both Task 1 modality types and both Task 2 difficulty levels as a function of ISI and level of practice. The latency data were subjects to an analysis of variance

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Insert Table 2 about here

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with Task 1 modality type (visual vs. auditory), Task 2 difficulty level (easy vs. difficult), ISI (0,50,100,200,600, and 1200 msec), level of training (first three sessions, second three sessions), and Task (1 or 2) all treated as within-subject variables. Task 2 difficulty level, $F(1,7)=19.22$, level of training,

Table 2

Task 1 and Task 2 reaction time (msec) and percent error in Experiment III as a function of ISI, Task 2 difficulty, and level of training.

		Task 1					
		ISI (msec)					
		0	50	100	200	600	1200
		First three days					
Visual-visual	Easy Task 2	531 (1.4)	530 (2.3)	527 (3.3)	525 (3.5)	506 (2.3)	521 (2.0)
	Difficult Task 2	576 (2.8)	569 (2.3)	569 (2.3)	554 (1.2)	560 (2.0)	544 (1.8)
Auditory-visual	Easy Task 2	562 (6.0)	573 (5.8)	548 (4.5)	547 (7.0)	548 (4.3)	549 (4.8)
	Difficult Task 2	619 (8.3)	611 (7.8)	598 (4.5)	603 (3.5)	603 (4.3)	602 (5.5)
		Last three days					
Visual-visual	Easy Task 2	443 (3.0)	442 (3.9)	443 (4.3)	452 (1.8)	441 (4.8)	442 (5.1)
	Difficult Task 2	448 (3.8)	452 (1.8)	446 (2.6)	442 (5.0)	448 (4.8)	436 (5.3)
Auditory-visual	Easy Task 2	417 (6.0)	438 (6.0)	435 (6.0)	428 (5.0)	423 (3.8)	435 (5.0)
	Difficult Task 2	411 (8.5)	425 (5.5)	425 (6.8)	427 (6.8)	411 (7.0)	419 (8.8)

Table 2 (cont'd)

		Task 2						
		ISI (msec)						
		0	50	100	200	600	1200	PRP effect (RT_0-RT_{1200})
		First three days						
Visual-visual	Easy Task 2	864 (5.0)	824 (7.1)	797 (4.8)	690 (4.1)	505 (3.8)	499 (4.3)	365
	Difficult Task 2	1094 (12.0)	1039 (9.3)	1013 (9.3)	929 (11.5)	728 (9.0)	663 (12.8)	431
Auditory-visual	Easy Task 2	970 (3.3)	921 (3.6)	860 (2.7)	756 (3.4)	524 (3.4)	536 (4 9)	434
	Difficult Task 2	1157 (9.1)	1101 (8.5)	1031 (10.3)	938 (11.8)	728 (17.3)	734 (10.3)	423
		Last three days						
Visual-visual	Easy Task 2	807 (3.8)	747 (3.8)	719 (3.1)	621 (5.6)	443 (2.9)	427 (2.0)	380
	Difficult Task 2	897 (8.1)	847 (8.1)	783 (9.5)	692 (10.0)	542 (11.1)	520 (8.1)	377
Auditory-visual	Easy Task 2	871 (4.0)	825 (4.3)	756 (2.1)	660 (3.3)	463 (3.3)	452 (2.5)	419
	Difficult Task 2	876 (8.3)	855 (11.5)	796 (6.3)	730 (8.3)	539 (9.8)	526 (6.5)	350

$F(1,7)=65.09$, ISI, $F(5,35)=61.19$, and task, $F(1,7)=59.90$ all showed main effects significant at beyond the .01 level. A significant interaction between ISI and task $F(5,35)=42.49$, $p < .01$, indicated that the PRP effect was isolated in Task 2. A significant interaction of task and difficulty level, $F(1,7)=12.59$, $p < .01$, shows that difficulty level manifested itself primarily in Task 2 performance. In addition, a significant interaction was obtained for all five factors, $F(5,35)=2.05$, $p < .05$.

In a subsequent analysis we used Fisher's least significant difference test to assess whether the magnitude of the PRP effect under the lower level of Task 2 difficulty differed between the auditory-visual and visual-visual conditions. It was significantly greater than that obtained under the visual-visual condition (LSD=37.5, $p = .05$). Again using the LSD test we examined the relation between easy and difficult Task 2 functions during the second half of training for visual-visual and auditory-visual conditions. To do this we compared mean latencies at the 0 and 1200 ISIs. The results of the analysis were that latencies were faster for the easy relative to difficult second task under the visual-visual condition at both intervals and for the auditory-visual condition at the 1200 msec but not the 0 interval.

General Discussion

Theoretical Considerations

The results of the third experiment suggest that several distinct types of processing limitation may operate under double-stimulation conditions. Indeed, the results put the issue that motivated the experiment into a new perspective. Two separate lines of theoretical thought are relevant to a comparison between the auditory-visual and visual-visual conditions of the study. According to one of these, capacity limitations lie within specific information processing structures in such a way that interference will occur provided a given, capacity-limited structure is overtaxed by the demands of time-sharing, but not otherwise

(Treisman, 1977). According to this view the visual-visual task pairing is apt to generate greater interference relative to the auditory-visual pairing because the common input modality in the former instance provides an added opportunity for specific structural overload.

An alternative conception is that attention is an isolable mechanism which functions in a manner analogous to a spotlight. Presumably some processing substructures require illumination by the spotlight in order to carry out their function, or at least to carry it out with optimum efficiency, whereas others do not (Erickson & Hoffman, 1973). Properly qualified, this conception can be shown to imply that a greater degree of interference will occur under the auditory-visual relative to the visual-visual condition. The necessary qualifications are that: 1) reorientation of the spotlight's focus takes time; the greater the extent of the relocation, the greater the time to relocate, and 2) reorienting *from the auditory to the visual modality* requires a more extensive relocation than reorienting within the visual system.

The results of Experiment III indicate that both of these conceptions have merit. Consistent with the "spotlight" model is the finding that the magnitude of the PRP effect at the lower level of Task 2 difficulty during the second three sessions is greater by 39 msec, $t(7)=2.41$, $p < .05$, under the auditory-visual relative to visual-visual conditions. This finding cannot be accounted for by differences in Task 1 latency across modality conditions since the two were about equal. Mean latency for Task 1 under the auditory-visual condition was 424 msec and under the visual-visual condition was 445 msec. All else equal, the shorter the Task 1 latency within the double stimuli paradigm, the shorter will be the latency to Task 2.

Before we consider the evidence provided in Experiment III for structural interference, it will be helpful to elaborate our interpretation of the data obtained from the auditory-visual condition. Of prime interest is the effect of Task 2 difficulty on the function relating Task 2 latency to ISI. During

the first half of training we see a slight (67 msec) divergence at the shorter intervals between the PRP functions for the easy and the difficult second tasks. However, during the second half of training the two functions converge, showing a difference at the 1200 msec interval of 74 msec and a difference at the zero interval of only 15 msec. Following the logic we have applied to the Karlin and Kestenbaum procedure, these data may be viewed as showing that response retrieval requires attention early in training, but not later on. Combining this idea with the notion that switching attention from one input modality to another requires time, yields the following account. During the early stages of training the requirement to attend and process inputs from the auditory modality prevents or substantially reduces the efficiency of the processing of stimuli input visually. In particular, response retrieval for visual inputs is not affected until after the retrieval requirements of the auditory (Task 1) stimulus have been met. Thus, the subject begins a trial focusing attention on the auditory modality. Following the completion of (at least) response retrieval for stimuli in that modality, attention is redirected to the visual modality, or to inputs received in that modality. At this point response retrieval for the visual stimulus has not occurred since this requires attention. Retrieval is now carried out, and a response is made to the Task 2 stimulus. The only change in processing we need to assume in order to account for performance during the second half of training is that response retrieval for the Task 2 stimulus can occur during the time attention is directed toward the modality of the Task 1 stimulus. In other words, at the higher level of training response retrieval becomes automatic, no longer requiring attention. One further aspect of the data must be dealt with, viz., the fact that the PRP functions for easy and difficult tasks actually diverge at the shortest intervals during the first half of the training. Our hunch is that this is due to the fact that the strength and therefore the retrieval speed of S-R connections defining the more difficult second task suffers more than those defining the easier second task from the removal of

attention during processing of the first task. But this probably reflects another aspect of the response selection issue.

Now consider the data produced under the visual-visual conditions. Here we see a tendency toward divergence at the shortest intervals during the first half of training and near perfect additivity (parallel functions) during the second half of training. Since we know or have reason to believe from the auditory-visual condition that response retrieval for Task 2 was well-automated for our subjects during the second half of training, why do the Task 2 functions fail to converge under the visual-visual condition at this same point in training? The answer must be that interference occurred between processes associated with Task 1 and Task 2 under the visual-visual condition, and this interference must have occurred prior to response retrieval.

This conclusion follows from two considerations. First, it seems unlikely that response retrieval itself is the source of the difficulty because, as we have seen, this process is automated by this point in the experiment. Second, the source of the problem cannot be in a process that follows response retrieval because: 1) as pointed out in our earlier discussion of the Karlin and Kestenbaum procedure, limitations following retrieval should yield convergence and 2) the processing demands of auditory-visual and visual-visual tasks are essentially identical following response retrieval; thus there exists no post-retrieval process unique to the latter condition which could produce the problem. On these grounds, we conclude that structural interference existed under the visual-visual condition and that this interference operated at a relatively early level of information processing. Our data shed little light on the mechanisms underlying this type of interference. It may be that in a complex visual field (more than one distinct stimulus) the build-up of code information is slowed for stimuli outside focal attention. Alternately, perhaps, it could be that multiple stimuli must compete for common analyzers with the result that non-priority inputs (i.e., Task 2 stimuli) must await the analysis of priority inputs before

they can be processed. We have no account for why all three subjects in Experiment II showed marked divergence of Task 2 functions throughout ten days of training, whereas subjects in Experiment III on the average exhibited no divergence during the last three of six days of training.

One further aspect of the data must be noted. During the second half of the experiment the magnitude of the PRP effect was 422 msec under the auditory-visual condition and 379 msec under the visual-visual condition. The total duration of processes required to complete the first task (i.e., RT_1) under these two conditions was 452 and 427 msec, respectively. In both cases the observed increase in Task 2 latency at the shortest interval almost equalled the total time required to complete Task 1 in these relatively well-trained subjects! It seems unlikely that an effect of this magnitude is wholly attributable to structural interference during input processing, or to inter-modal attention shifts. Our hunch is that this added source of interference occurs in response initiation (Keele, 1973), as previously described in this report. Our present data do not permit us to measure the contribution of this factor, however.

Implications for the Study of Time-Sharing as a Unitary Ability

The preceding analysis led to the conclusion that several types of processing limitation may be manipulated in performance on even relatively simple double-stimulation tasks. Early in training, response selection requires attention: Consequently this operation cannot initially be carried out simultaneously with other control operations. This problem appears to dissipate with training, however, and retrieval gradually automates. Of course the speed with which automaticity is achieved will be affected by many factors, including the complexity of component tasks, their number, task complexity, similarity among task aspects, differences among individuals, and the like. A second and more enduring limitation is response initiation, the translation of the retrieval response code into motor action. A third problem is structural interference, which, in the present situations, refers to a limitation uniquely manifested

when a common input modality is shared by two or more uncorrelated inputs. A fourth problem appears when contiguous inputs occur in different modalities: when one modality is attended, the processing of inputs through another modality may be retarded or prevented. Time-sharing is not a unitary process: Performance on different task combinations and at different training levels will unquestionably reflect these limitations to differing extents. Consequently one can argue that time-sharing is a general (transituational) ability only to the degree that measures of the limitations we have identified are correlated. Because we do not have satisfactory measures of the limitations in the present experiments, we cannot at this point assess the degree of their relatedness. However, given the conceptual dissimilarity of the processes responsible for them, we doubt that substantial correlations will be obtained.

Assuming it is correct, what does this conclusion imply concerning the applied utility of the time-sharing concept? The problem may not be as serious as it would at first seem. It may still be possible to predict individual performance in complex task situations: to do so simply requires an analysis of the criterion situation of interest to determine precisely which of the limitations we have discussed will be operative. Prediction can then be based on the pattern of limitations exhibited by the individual relative to the pattern of demands imposed by the criterion. The problem is very much like that confronted by those interested in assessing athletic ability. The current evidence suggests that there exists no general athletic ability, but rather a set of more specific motor aptitudes. Some individuals are strong on some of these and a few individuals happen to be strong on most or all of them, even though they are independent factors. It is the latter set of individuals who probably have led to the idea of a unitary general athletic ability.

This report began with a description of three problems that have recently been raised for the notion of a general time-sharing ability. What do our data have to say concerning these problems?

First, our findings shed considerable light on Sverko's (1977) inability by correlational means to detect the existence of a general time-sharing ability. It is quite apparent from a consideration of the tasks used by Sverko that they tap differing patterns of the capacities we have described. His failure to find correlations across task pairings in time-sharing deficit is supportive of our idea that the specific capacities that together form one's time-sharing ability are largely independent of one another. For the same reasons, our analysis makes Sverko's failure totally reasonable. His tasks and analysis would yield evidence for a time-sharing ability only if that ability were unitary or comprised of highly correlated sub-abilities.

Second, we have found little meat in Logan's argument that information-processing capacity is not required during the actual performance of multiple tasks, only in their preparation. Indeed, as we have seen, the present data show that a number of discernable limitations may be tapped by the performance of even simple task combinations. In light of our data, it appears likely that Logan's results were due to an artifact, viz., an ability on the part of his subjects to disregard one (the memory task) of the two tasks they performed on each trial while they devoted more or less full attention to the other (the visual search task).

The third problem stemmed from the findings of Damos and Wickens (1977) which led them to conclude that time-sharing is a skill rather than an ability. The finding on which this conclusion was based is that practicing the time-sharing of a particular pair of tasks seems to improve performance on a subsequent task pairing, even though both component tasks were different from those originally practiced. We have already noted that evidence of this sort does not in fact necessarily indicate that time-sharing is a skill rather than an ability. The indication may simply be that time-sharing has a skill component. Our results shed no further light on the Damos and Wickens results. The only capacity limitation clearly exhibiting adaptive changes with practice in our

experiments is response selection or retrieval. However, response selection is specific to the tasks(s) involved. Consequently it should exhibit little or no transfer.

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